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ACTIVATED SLUDGE FROM COMMON FOODS FOR RADIOACTIVE WASTE TREATMENT

(LABORATORY STUDIES)

by

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ACTIVATED SLUDGE FROM COMMON FOODS FOR RADIOACTIVE WASTE TREATMENT*

(LABORATORY STUDIES)

The common purpose of the activated sludge process is to remove organic material from suspension and solution. As applied to the treatment of radioactive waste the purpose is ~~rather~~ to remove inorganic isotopes from very dilute waste water solutions. The inorganic isotopes have only very minor nutritional value for microbiological systems. Consequently, for application to radioactive waste treatment, activated sludge requires supplemental organic food for the excess production of zoogleal growths which can be removed when the radioactivity is concentrated in the biological floc. A delineation of the problem of radioactive waste disposal by activated sludge has been made by the senior author (8).

It is the purpose of this paper to present laboratory studies on the choice and technique of feeding common foods and the supplemental nutrients necessary to maintain activated sludge under satisfactory control with respect to the effluent quality, sludge settleability and production of excess quantities of sludge.

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Experimental Method

Activated sludge aerators consisting of nine-liter pyrex serum bottles were filled with eight liters of mixed liquor and aerated for 23 hours per day by means of compressed air through a ball diffuser resting on the bottom of the bottle. Air was supplied at a rate

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sufficient to prevent sedimentation of sludge. Each morning, except Saturday, the aeration was interrupted for one hour or less by withdrawing the air diffuser ball. One or more liters of mixed liquor was poured off for settling and other tests. When tests indicated that sludge should not be wasted the sludge from the liter settling test was returned to the aerator. The mixed liquor remaining in the bottle was allowed to settle quiescently for 30 minutes after which the supernatant was siphoned off leaving only two liters of liquor containing the activated sludge. Occasionally, when poor settling sludges were encountered, only the clear supernatant was drawn to near the sludge blanket, leaving more than two liters of thin sludge.

The total volume withdrawn from the aerator was immediately replaced to the original eight-liter volume with Cincinnati tap water containing organic food and mineral nutrients. Since the aerobic oxidation of organic food and nitrogen gave rise to acid conditions which were detrimental to active biological growths, the pH of the new batch of mixed liquor was adjusted with a solution of 25 per cent NaOH. The procedure was to adjust the pH to 9.0 to 9.5 at zero hour aeration. Usually the pH fell to 7.0 to 7.5 after 23 hours of aeration. Occasionally one pH adjustment would not sustain a favorable pH range so a second pH adjustment was made in the late afternoon. After the addition of the nutrient and pH adjustment the air diffuser ball was placed in the bottle and aeration begun. An experiment was usually continued for two weeks or more after

equilibrium control had been established before a change in variables was made. The mixed liquor suspended solids varied from 2,000 to 8,000 p.p.m. Usually a smaller variation of 3,000 to 5,000 p.p.m. suspended solids was maintained for a given experiment.

Activated Sludge Feeding Technique

The initial source of activated sludge was prepared by aerating sewage. Gradually the sewage feed was replaced with feeds from common food. The sludges produced from one series of experiments were pooled and used to start succeeding experiments.

The general technique of feeding the activated sludge consisted of adding a weighed amount of food and superphosphate, and stock solutions of water soluble minerals to the sludge diluted with Cincinnati tap water. The concentrations of salts present in the tap water are shown in Table 1. In some experiments 10 per cent of the total dilution water was raw sewage. After preliminary experimentation with different kinds and concentrations of flour and sugar more extensive studies were conducted on sludges fed daily with six grams of wheat flour plus two grams of dextrose and a variable quantity of mineral nutrients. The eight grams of flour-dextrose feed to eight liters of mixed liquor was referred to as a feed of 1,000 p.p.m. However, based on 25 per cent return of sludge, the food amounted to 1,250 p.p.m. per 23 hours which is theoretically comparable to four, six hour aeration periods each fed 312 p.p.m. of food having a 5-day B.O.D. of 215 p.p.m.

Control Indices

The characteristics of sludge and an accounting of the amount of sludge produced was determined five times each week by determining (a) the sludge volume after 30 minutes settling in a liter graduate, (b) the mixed liquor suspended solids in 10 to 25 ml. of sample and often the volatile solids of same by the Gooch Method, and (c) the supernatant suspended solids, oxygen consumed value and other tests as required. The sludge volume index (S.V.I.) [13] was calculated from (a) and (b). The suspended solids of the mixed liquor were compared with that of the previous day to calculate the daily gain or loss of activated sludge.

Results

For several weeks of study six aeration bottles originally containing activated sludge produced from sewage were acclimated to common food nutrients. During this period it was deemed desirable to use a mineral water containing an excess quantity of nitrogen, phosphorous, potassium and trace quantities of other mineral elements while altering and increasing the organic nutrients.

The mineral water selected was distilled water fortified with 42 p.p.m. KH_2PO_4, 25 p.p.m. $MgSO_4 \cdot 7H_2O$, 25 p.p.m. $CaCl_2$, 0.135 p.p.m. $FeCl_3 \cdot 6H_2O$ and 50 p.p.m. $(NH_4)_2SO_4$. The pH was adjusted to 7.2. In some subsequent studies five times the above concentration of salts were used and the $(NH_4)_2SO_4$ replaced with $(NH_4)_2HPO_4$, NH_4NO_3 or KNO_3.

The initial foods selected included soya, graham and wheat flour, corn meal, and each of these foods supplemented with dextrose. According to Horvath [14] the percentage composition of soya bean flour is 7.65 water, 40.65 protein, 20.38 fat, 23.5 carbohydrate, 6.08 ash, 3.08 phosphatides as lecithin (P_2O_5 x 11). The percentage composition of wheat flour has been reported [15] to be 11.9 water, 13.8 protein, 1.5 fat, 72.7 carbohydrate, 0.014 calcium, 0.010 phosphorous, 0.010 iron and 0.021 copper. During the initial acclimation period as low as 200 p.p.m. of common foods were fed daily with or without a volume of sewage equal to 10 per cent of the aeration volume. The concentration of food was gradually increased to as high as 1,000 p.p.m.

The B.O.D. (5-day 20°C.) and the Oxygen Consumed (Acid Dichromate) [5] of the foods used is presented in Table 2. The data show that corn meal has a relatively low B.O.D. of 0.18 grams of B.O.D. per gram of food. Wheat flour and dextrose have B.O.D's. of 0.65 and 0.75 grams per gram of food. Often a mixture of three parts of wheat flour and one part of dextrose was used as a food. The theoretical B.O.D. of the mixture is 0.67 grams of oxygen per gram of mixture compared to an average observed value of 0.70.

The suspended solids of the mixed liquor in the initial experiments increased from a "seed" concentration of 150-250 p.p.m. to over 3,000 p.p.m. after one or more weeks of feeding. During the first two or more months of experimentation complete sludge control was

unobtainable because the supernatants of the aerators often contained 75 to 200 p.p.m. non-settleable suspended solids. Nevertheless, these studies were extremely valuable in furnishing clues as to how best to feed and maintain control of activated sludge.

It was observed that a large part of the graham flour and particularly the corn meal was not attacked or converted to zoogleal cell substance but accumulated in the sludge more or less unchanged. The rest of the foods, singularly or in mixture, produced sludges which microscopically appeared to be typical zoogleal masses with only a small number of stalked and free swimming ciliates. The effluents or supernatants contained a large amount of finely dispersed zoogleal floc and colloidal solids particularly for daily feeds of less than one part of food for each two parts of mixed liquor suspended solids. Sludges supplied with 500 to 750 p.p.m. of wheat flour tended to produce foaming for some hours after feeding until the mixed liquor suspended solids reached levels of over 3,500 p.p.m.

It was found that the pH of the mixed liquor decreased from an initial range of 7.0 to 7.4 to the range 3.9 to 4.6 in a 23-hour aeration period. When the nitrogen source in the mineral water was changed from ammonium sulfate to potassium nitrate the pH decreased to the range 6.0 to 6.5 and the supernatant quality improved remarkably. Apparently greater improvement might be affected by control of pH at a higher value.

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The preliminary studies and a review of the literature clearly indicated the direction of further experimentation. It would be necessary to limit the kind of food used for developing activated sludge and concentrate on the necessary measures to control the sludge characteristics and behavior. After considering the availability and cost of foods in relation to the zoogleal sludge produced, two foods, wheat flour and dextrose, were selected for further experimentation.

The Effect of pH Adjustment on the Control of the Characteristics of Activated Sludge Fed on Wheat Flour and Dextrose

Two experiments were designed to reveal the need of controlling the pH of the mixed liquor during the aeration period. In each experiment, a control sludge without pH adjustments was fed identically to a sludge with pH control. The pH control was achieved by adding 15 to 80 p.p.m. sodium hydroxide to the mixed liquor. A pH of 7.0 at the end of the aeration period was obtained by adding sufficient caustic to raise the pH to 9.0 at the beginning of aeration and again after six hours of aeration.

The sludges, containing 3000-5000 p.p.m. aerator suspended solids, were fed 1,000 p.p.m. food daily consisting of 750 p.p.m. wheat flour and 230 p.p.m. dextrose. The feed was added to a mixed liquor in Cincinnati tap water fortified with ammonium nitrate and superphosphate for one pair, Sludge "A". Distilled water fortified with other minerals in addition to ammonium nitrate and superphosphate was used for a second pair, Sludge "B". The pertinent results of these experiments

in a two-week study period are presented in Table 3. The mixed liquor from tap water in Sludge "A" was fortified daily with 35 p.p.m. of NH_4NO_3-N and 1.9 p.p.m. phosphate as superphosphate whereas the mixed liquor from distilled water in Sludge "B" was fortified daily with 53 p.p.m. of NH_4NO_3-N, and 20 p.p.m. KH_2PO_4-P, 55 p.p.m. $CaCl_2$, 100 p.p.m. $MgSO_4$ and 1.1 p.p.m. $FeCl_3$.

Without pH control in Sludge "A" it is to be noted that the average suspended solids of the supernatant was 140 p.p.m. as against 60 p.p.m. with pH control in the range 6.7 to 9.0 throughout the aeration period. Without pH control, the mixed liquor pH of near 7.0 immediately after feeding decreased to an average of 6.6 or a minimum of 3.9 after 23 hours of aeration.

Without pH control in Sludge "B", it is noted in Column 4 of Table 3 that the average suspended solids of the supernatant liquor was 170 p.p.m. as against 30 p.p.m. when the pH was controlled. It may be observed that Sludge "B" without pH control resulted in a poorer supernatant and lower average and minimum pH values after 23 hours aeration than Sludge "A". With pH control Sludge "B" required daily from 50 to 70 or an average of 60 p.p.m. NaOH whereas Sludge "A" required 15 to 80 or an average of 50 p.p.m. The increased acid production in Sludge "B" as compared to Sludge "A" may be ascribed to the utilization and nitrification of the higher ammonia-nitrogen content added to Sludge "B".

Either with or without pH control the sludges were settled readily to S.V.I. values of 49 to 69 and the percentage of added food appearing as a gain in sludge solids amounted to from 260 to 310 milligrams of sludge per gram of food added.

In order to confirm the value of pH control both of Sludges "B" were fed for an additional two weeks with pH adjustment at a slightly higher level by adding daily 125 to 190 or an average of 137 p.p.m. NaOH. After 23 hours of aeration the pH varied from 7.2 to 8.6. There was an immediate improvement in the supernatant quality of the sludge whose pH had not been previously controlled and both sludges produced supernatants having an average suspended solids of 35 p.p.m. The gain in sludge solids was 280 mg./g. of food and the sludge settleability was 55 to 60 S.V.I.

The Phosphorous and Nitrogen Requirements of Activated Sludge Produced from Wheat Flour and Dextrose Food

A. Sludges Fed 1,000 p.p.m. Food

During a two-week period ten sludges were each fed daily with 750 p.p.m. wheat flour and 250 p.p.m. dextrose in Cincinnati tap water fortified with ammonium nitrate and superphosphate. The study was continued for another two weeks with one-half the ration or a feed of 500 p.p.m. food daily. In all cases the pH of the aeration mixture was adjusted at the time of feeding to pH 9 with NaOH so that it remained substantially above pH 7 throughout the aeration period.

The results of these studies are presented in Table 4. Sludge No. 1 was a control sludge fed 1,000 p.p.m. food. Each day Sludges Nos. 2 to 5 were fed 1,000 p.p.m. food and superphosphate additions equal to 2.9 p.p.m. phosphorous (Column 3) and ammonium nitrate additions of 0, 25, 50 and 100 p.p.m. nitrogen, respectively, (Column 2). Sludge Nos. 6 to 10 were similarly each fed 1,000 p.p.m. food and ammonium nitrate additions of 50 p.p.m. nitrogen each and superphosphate additions of 0, 1.45, 2.9, 5.8 and 11.6 p.p.m. phosphorous. An ample supply of activated sludge produced from wheat flour-dextrose food in previous tests were pooled and an amount equal to about 2,000 p.p.m. mixed liquor suspended solids was used as a starter. During the course of the experiment activated sludge was wasted to maintain a suspended solids concentration in the mixed liquor of from 2,000 to 6,500 p.p.m. as shown in Column 4. The percentage fixed solids or ash of the dry sludge solids is shown to vary from 8.1 to 16.3 in Column 5.

The gain in sludge solids per feeding was measured as an increase of suspended solids in the mixed liquor or sludge solids that were wasted exclusive of loss of suspended solids in the supernatants withdrawn. Column 6 shows that the gain in sludge solids in the first ten sludges varied from 220 to 380 p.p.m. per 1,000 p.p.m. of feed.

The index of effluent quality is shown in Column 7 as the average quantity of suspended solids in the supernatant withdrawn before each feeding. Average effluents containing 17 to 36 p.p.m. of suspended solids were obtained.

Determinations for ammonia nitrogen by direct Nesslerization, nitrate nitrogen by the disulfonic acid method and nitrite nitrogen were made on the filtered supernatants. Only traces of nitrite nitrogen (less than 0.3 p.p.m. in all except Sludge No. 7 which had an average of 1.05 p.p.m.) and traces of ammonia nitrogen (less than 0.1 p.p.m.) were found in the supernatants. Incidentally the Kjeldahl and ammonia nitrogen values were identical in a number of spot tests. The average nitrate nitrogen in p.p.m. found in the supernatants is tabulated in Column 8. The data may be used to show that substantially all the nitrate nitrogen added as ammonium nitrate was discharged in the supernatant. A variable amount of the ammonium nitrogen which was nitrified during the 23 hour aeration period was also discharged in the supernatant.

The wheat flour feed of 750 p.p.m. contained 28 p.p.m. of organic nitrogen. Since in Sludge No. 1 the supernatant had 4.8 p.p.m. NO_3-N, it may be assumed that a nitrogen deficiency did not exist even when no ammonium nitrate was added. However, when ammonium nitrate was added the ammonia disappeared through synthesis to cellular material, losses of ammonia by aeration of alkaline liquor and by nitrification. Calculations show that of the sludges fed 50 p.p.m. nitrogen, half of which was ammonia, from 0.5 to 16.5 p.p.m. of the ammonia was nitrified to nitrates.

The settleability of the sludge is shown in Column 9. A sludge settleability value of less than 90 usually permitted the withdrawal of 75 per cent of supernatant from the mixed liquor. This value may be selected as the point below which the control of operation was easy. Values progressively higher than 90 made it increasingly difficult to maintain control of the supernatant quality. An inspection of the average sludge settleability values indicates that Sludges Nos. 1, 5, 6 and 7 had borderline or unsatisfactory settling qualities. Three of these sludges were fed less than 1.5 p.p.m. phosphorous. Six of the first ten sludges which were fed 2.9 p.p.m. or more phosphate phosphorous and zero to 50 p.p.m. NH_4NO_3-N produced sludges with satisfactory settling indices. It was noted, moreover, that the S.V.I. value increased progressively with the addition of increasing amounts of ammonium nitrate. In fact, Sludge No. 5, to which had been added 100 p.p.m. NH_4NO_3-N, again produced an unsatisfactory settling index. The tendency of excess ammonium salt to produce less settleable sludges is clearly shown in Figure 1 where the ammonium nitrate addition has been plotted against the sludge settleability for sludge feeds fortified with 2.9 p.p.m. phosphorous. The cause of this relationship has not been clearly defined but the nitrogen balance indicates that in the transformation of organic and ammonia nitrogen there is a substantial loss of nitrogen presumably through denitrification or the diazo reaction to free or gaseous nitrogen. The literature[1,7,11]

and our observations indicate that occluded nitrogen gas causes bulking or rising sludge.

It may be concluded from these experiments, which are examples of repeated observations, that between 1.5 and 3.0 p.p.m. of phosphate phosphorous in addition to the traces present in the flour was beneficial to the control of sludge settleability providing excessive amounts of ammonium salts were absent.

An analysis of the phosphate balance indicated that 2.4 plus or minus a standard deviation of 0.5 p.p.m. of the added phosphorous was removed from the supernatant liquors in those sludges which were fed from 2.9 to 11.6 p.p.m. PO_4-P.

The organic nitrogen in the flour, amounting to 28 p.p.m. in the mixed liquor, supplied the necessary nitrogen needs of 1,000 p.p.m. of food. The carbon content has been estimated to be 397 p.p.m. or a carbon-nitrogen ratio of 14:1. Additional nitrogen in the form of ammonium nitrate was not necessary. When 100 p.p.m. of nitrogen was added or the carbon-nitrogen ratio was 3:1 a sludge of poor settleability developed.

B. Sludges Fed 500 p.p.m. Food

After two weeks of study the amount of food and nitrogen fed Sludges Nos. 1 to 10 was decreased by one-half but the phosphate additions were not changed. The average results of this study over a two-week period are also presented in Table 4, Sludges Nos. 11 to 20, inclusive.

As on the higher rate of feeding experiments, it may be observed that Sludges Nos. 11 and 17, which received zero and 1.45 p.p.m. PO_4-P, respectively, tended to have relatively poor settling characteristics. All but one of the sludges which received 2.9 p.p.m. or more of phosphate phosphorous had satisfactory settling characteristics. Again there was a tendency of forming sludges with poorer settling indices when increasing amounts of ammonium nitrate and 2.9 p.p.m. phosphorous were added to the sludges.

When nitrogen balances were made on Sludges Nos. 11 to 15 inclusive, it was found that 10.1 to 14 p.p.m. of the added nitrogen was not recovered as nitrate, nitrite or ammonia nitrogen in the supernatant but had presumably been incorporated in cell substance or volatilized. Furthermore, it was apparent that no additional nitrogen other than the 14 p.p.m. of organic nitrogen in the flour was necessary for 500 p.p.m. of flour-dextrose food.

Of greater importance, however, is the observation that the supernatant liquors of Sludges Nos. 11 to 20 were decidedly unsatisfactory. The suspended solids in the supernatants averaged from 36 to 130 p.p.m. while the increase or gain of sludge solids in Sludges Nos. 12 to 19 varied from 5 to 95 p.p.m. per 500 p.p.m. food. An average of only 90 p.p.m. sludge solids, including the suspended solids of the supernatant, was produced from 500 p.p.m. food.

It was concluded that the sludges were existing on a starvation diet which resulted in unsatisfactory supernatants, a deficient production of sludge for wasting, and, in the absence of adequate phosphate, sludges having poor settling characteristics.

The Nutritional Value of Potassium Additions

In order to determine whether more than the 2 p.p.m. of potassium in the Cincinnati tap water was needed for the nutrition of sludges fed 750 p.p.m. of wheat flour and 250 p.p.m. of dextrose, five sludges prepared from a common seed were dosed daily with 0, 13.1, 26.2, 52.4 and 104.5 p.p.m. of additional potassium per 1,000 p.p.m. of food for over two weeks. The results are tabulated in Table 5. The food fed Sludges Nos. 1 to 5 was fortified with 2.9 p.p.m. phosphorous. The results show that there was no significant benefit by adding more than the 2 p.p.m. of potassium in the tap water. The relatively high gain of sludge solids amounting to over half of the food added in this experiment was of questionable significance.

Five other sludges having the same seed were dosed with similar quantities of potassium but the feed of 1,000 p.p.m. flour-dextrose in Cincinnati tap water was not fortified with phosphorous but was dosed instead with 50 p.p.m. of ammonium nitrate nitrogen. The results presented in Table 5, Sludges Nos. 6 to 10, show that additional amounts of potassium over that present in the tap water were without effect on the behavior of the sludge. The deteriorated supernatant can be ascribed to phosphate deficiency and possibly excess nitrogen.

Confirmation Study

An experiment to verify the nutritional needs of a sludge on a long time basis was begun by adding to four liters of acclimated returned sludge 12 liters of Cincinnati tap water fortified with

0.05 grams (3.1 p.p.m.) of phosphorous as superphosphate fertilizer and organic feed consisting of nine grams of wheat flour and three grams of dextrose (i.e. 750 p.p.m. food) for each of six days per week. After 14 days the amount of organic feed was increased to 12 grams of wheat flour and four grams of dextrose (i.e. 1,000 p.p.m.) per day for 94 additional days. The results of this experiment are summarized in Table 6. The average results indicate that during a total of 108 days of continuous operation a very good control of sludge behavior was achieved. Difficulty was experienced in withdrawing over 70 per cent of the aerator volume as relatively clear supernatant on 40 days and on 10 days the suspended solids of the supernatant exceeded 50 p.p.m. The average gain in activated sludge solids amounted to 30 milligrams per gram of food for Period I compared to 394 milligrams per gram of food for Period II. Thus, it is apparent that for high aerator solids of 4,000 to 6,000 p.p.m. suspended solids and ample air for an aeration period of 23 hours per day, a daily feed of 750 to 1,000 p.p.m. of flour-dextrose food is necessary to produce 30 to 400 p.p.m. of excess sludge.

In order to maintain the day by day control of the sludge it appeared necessary to add 3.0 p.p.m. of phosphorous as superphosphate to the aeration liquor and adjust the pH to the range 7.0 to 9.5. Anticipated difficulties were forseen by trends in poorer effluent quality or poorer settleability of the sludge. Based on past experiences minor additions of nitrogen or phosphorous were made.

In each instance, improvement in the control was obtained. These experiences were as follows:

1. When the sludge volume per gram sludge approached 100 ml., sludge was wasted or additional phosphorous up to 5.8 p.p.m. was added for a few days.
2. If suspended solids in the supernatant were over 30 p.p.m. and the sludge volume per gram sludge solids was 50 ml. or less the mixed liquor was dosed for several days with ammonium salts in amounts of as much as 70 p.p.m. nitrogen. These control measures were not found to produce immediate corrections. Usually, however, in 24 to 48 hours noticeable improvement in sludge quality was found.

Discussion

The annual reviews (10) on sewage and industrial waste treatment contain numerous references pertaining to difficulties experienced with the control of activated sludge. In general, it may be summarized that the treatment of sewage and industrial wastes high in carbohydrate content results in activated sludge having poor settling qualities and usually poor effluents. A preponderance of filamentous organisms is usually associated with these sludge characteristics. It appears significant, however, that Morgan and Beck (6) were able to control bulking and excessive sphaerotilus growths in activated sludge from sewage containing brewery slop by heavy lining.

Ruchhoft and Watkins [9] studied the filamentous organism involved and found that the organisms could not be cultured at pH less than 6.0 or more than 8.8. The successful treatment of dairy wastes at two activated sludge plants was reported by Montagna [4]. In many respects these waste treatment plants operated similarly to our laboratory experiments. The influent of the Somerset, Pennsylvania plant was treated with a slurry of lime to a pH of 8 to 9, mixed and settled. The benefit claimed for lining was to coagulate the casein and prevent septicity in the primary settler. The primary settler effluent flow of 50,000 gallons per day had an average five-day B.O.D. of 545 p.p.m. and a maximum B.O.D. of 1,800 p.p.m. The flow was treated in a 60,000 gallon aerator with a return flow from the bottom of a secondary settling tank amounting to 40 to 50 per cent of the waste flow. The pH of the aerator influent was lowered by aeration to 7.6-7.8. The effluent B.O.D. averaged 7.4 p.p.m. in three years of operation with a maximum value of 16.5 p.p.m. based on periodic sampling by the Pennsylvania Department of Health. The suspended solids concentration in the mixed liquor was not reported but it was stated that in the three year period no activated sludge was wasted except on two occasions when the plant was shut down for general cleaning. The operation of the Bremen, Ohio milk waste plant was similar and produced effluents of excellent quality. It is speculated that the liming procedure for chemical precipitation in the primary treatment was particularly beneficial in maintaining a favorable pH range in the

aerators and resulted in an excellent performance record. Furthermore, the average loading rate of 545 p.p.m. B.O.D. for the 24 hour aeration period was sufficient to prevent overaeration or a loss of B.O.D. to the effluent but insufficient to accumulate sludge that would have to be wasted.

The above plant studies on dairy wastes are to be compared with the laboratory studies on activated sludge fed flour-dextrose where it was found that 500 to 750 p.p.m. of food having a B.O.D. of 350 to 525 p.p.m. after aeration for 23 hours produced little or no excess sludge while a feed of 1,000 p.p.m. food or 700 p.p.m. B.O.D. would yield 250 to 400 p.p.m. of excess sludge.

It is probable that milk wastes represent a balanced diet for activated sludge with respect to the carbon and nitrogen ratio as well as the adequacy of phosphorous, potassium, calcium, sulfur and other mineral nutrients.

According to Sawyer (12) activated sludge lost its ability to oxidize nitrogen when the B.O.D. to NH_3-N ratio exceeded 16:1 while the highest rate of oxidation was found at a B.O.D. to NH_3-N ratio of 8.2:1. The food used in Sawyer's studies contained considerable organic nitrogen in addition to the ammonia nitrogen. If this is included and it is assumed the B.O.D. was exerted from organics containing 40 to 50 per cent carbon it may be calculated that the carbon-nitrogen ratio in his studies varied from 3:1 to 7:1 or a rather liberal amount of nitrogen.

Ingols and Heukelekian [3] experimented with activated sludge fed on glucose and urea in New Brunswick, New Jersey tap water fortified with phosphate and bicarbonate buffers (9 p.p.m. phosphorous and 11 p.p.m. potassium). They concluded that a carbon-nitrogen ratio of 8:1 was optimum for retarding bulking. Heukelekian and Littman [2] found the carbon-nitrogen ratio of activated sludge solids to be 5.7:1 from which it was calculated that the pure culture sludge consisted of 65 per cent protein and 35 per cent carbohydrate.

Wakesman [16] reported "Nitrification was found to be checked when the carbon-nitrogen ratio in the soil is 13-15 to 1, but not when the ratio is 11-11.6 to 1. When molasses was added to the soil, nitrification was stopped when the ratio was about 11:1, but was not injured when the ratio was less. However, the addition of carbon sources not readily available, such as butyric acid and alcohol, did not injure nitrification at a ratio of 14:1 but did injure it at a higher rate". Some ammonia was liberated by Bacillus subtilus in the decomposition of alfalfa meal which has a carbon-nitrogen ratio of 16:1 while only traces of ammonia were liberated by fungi.

In the flour-dextrose studies it was found that an organic nitrogen content of 28 p.p.m. from wheat flour seemed to satisfy the nitrogen requirements of activated sludge fed 1,000 p.p.m. food. It was calculated that the food contained 297 p.p.m. flour carbon and 100 p.p.m. dextrose carbon or a total of 397 p.p.m. carbon per 1,000 p.p.m. food. Thus the carbon-nitrogen ratio was 397:28 or about 14:1. Fifty p.p.m. of additional nitrogen as ammonium nitrate

was added in some experiments without significant effect. Since nitrate nitrogen was recovered in the supernatant in excess of that added a new ratio based on organic and ammonium nitrogen may be calculated, i.e. 397:28+25 or 7.5:1 carbon to nitrogen in the fortified food. Thus a food having a carbon to nitrogen ratio of 14:1 to 7.5:1 can be satisfactorily treated by the activated sludge process providing phosphorous, other mineral nutrients and the pH are adequate. However, when 50 p.p.m. ammonium nitrogen was added producing a carbon-nitrogen ratio of 397:28+50 or 5:1 in the food the sludge developed excessive bulking characteristics. Again it is assumed that the added nitrates did not contribute to the deleterious effect of the added nitrogen. Rather, the nitrification of the ammonia which was eventually lost to the atmosphere or appeared as nitrites and nitrates in the supernatant was credited for the bulking tendencies of the sludge.

The phosphorous requirements in the activated sludge experiments appeared to be critical if present in concentrations less than 2.9 p.p.m. phosphate phosphorous added per 1,000 p.p.m. of food. Thus the critical carbon-phosphorous ratio above which the supernatant will be impaired is 397:2.9 or about 135:1. Presumably, all of the added phosphate was soluble and available. Tests of the supernatants indicated that if 2.9 p.p.m. or more of phosphorous was added all but 2.4 p.p.m. plus or minus a standard deviation of 0.5 was recovered as soluble phosphate in the supernatant. From this average utilized value a new critical carbon to phosphorous ratio of 397:2.4 or 165:1 may be calculated.

It is interesting to note that the minimum need of phosphorous by azotobacter was reported by Wakesman (17) to be 2.46 mg. per gram of glucose feed. The value found for activated sludge checks the value found for the aerobic soil organism.

The potassium requirements of the activated sludge experiments did not appear critical with tap water diluent containing 2 p.p.m. potassium. Thus a carbon-potassium ratio of 397:2 or about 200:1 appears adequate. Decreasing ratios to 3:1 had an insignificantly beneficial effect.

Activated sludge developed from food containing three parts of wheat flour and one part of dextrose has a golden-brown color typical of well conditioned activated sludge. It is quite flocculent and settles rapidly. It tends to become more granular if the percentage dextrose in the food is increased. The sludge ash rarely exceeds 12 per cent of the dry solids. To develop sludge from flour-dextrose food the sludge must first be acclimated. This is accomplished by increasing the amount of feed gradually. Foaming occurs during the first two weeks of feeding. Thereafter foaming ceases except during the first few minutes of aerating a new feed. As much as 5,000 p.p.m. of food has been fed daily to 5,000 p.p.m. aerator suspended solids with only slight foaming in an acclimated sludge.

The pH must be maintained at over 7.0 or the supernatant will be charged with suspended solids. Clear effluents were obtained when 1,000 p.p.m. of food was added daily to 3,000 to 5,000 p.p.m. aerator suspended solids. When lesser amounts of food were added the supernatant contained more nonsettleable sludge floc.

The sludge settleability appeared sensitive to the phosphate phosphorous in the food. When the food contained less than about 3 p.p.m. phosphorous the sludge index rose and excessive suspended solids appeared in the effluent. Occasionally when the sludge index tended to rise toward an uncontrollable value with a phosphorous feed of 2.9 p.p.m. the amount of phosphorous in the feed was doubled. An almost immediate decrease in the sludge index resulted. When the sludge volume index was less than 50 and the supernatant suspended solids exceeded 30 p.p.m., an improvement in the supernatant quantity could be achieved by adding supplemental nitrogen as ammonium nitrate. The sludge index would then rise moderately. The sludge index could be lowered by increasing the percentage of dextrose in the food. A flour to dextrose ratio of 1.67:1 or 2:1 produced a more granular sludge which settled and filtered more readily than sludge from food having less dextrose. No spurious growths of filamentous organisms interferred with the experiments adjusted in the pH range of 9.5 to 7.0.

Although most of the experiments herein reported deal with the production of activated sludge from flour-dextrose food it is surmised that a multitude of common foods or wastes might be used. In each case, it would be necessary to investigate the detailed factors for providing a balanced diet. Presumably the nitrogen and phosphorous requirements would be of paramount importance while other mineral nutrients, although important, may be found in the waste or food selected for study.

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It seems pertinent to suggest that although these nutritional studies were made on activated sludge the results would seem to be equally applicable to biological filters.

Summary

Laboratory studies in nine-liter bottles on the development and control of activated sludge fed with common foods were made. One of the objectives of these studies was the control of a biological process having adsorptive properties which may be used for removing radioactive wastes from liquors normally deficient or devoid of organic food for zoogleal organisms.

Several foods were studied but a food consisting of three parts of wheat flour, patent (bleached white flour) and one part of dextrose was selected for use and studied in greater detail. This food produced a fast growing sludge having rapid settling characteristics and satisfactory effluents in a 23 hour aeration period provided:

1. The sludge maintained at 3,000 to 5,000 p.p.m. suspended solids was fed 1,000 p.p.m. of flour-dextrose food daily.
2. The mixed liquor was adjusted with sodium hydroxide to pH 9.0 to 9.5 after feeding so that a pH of not less than 7.0 persisted throughout the aeration period.
3. The food was fortified with superphosphate fertilizer equivalent to 2.9 p.p.m. phosphorous in the mixed liquor. The carbon to phosphorous ratio of 135-165 to 1 appeared optimum. A deficiency of phosphorous produced effluents

charged with suspended solids. Occasionally twice as much phosphorous was necessary to lower the sludge index and improve the effluent quality.

4. The nitrogen in the flour amounting to 28 p.p.m. organic nitrogen met the sludge requirements. Additional ammonium nitrogen improved the effluent quality of sludges having a low sludge index. A carbon-nitrogen ratio of 14:1 appeared adequate.

Conclusions

It is concluded that should it be desirable to utilize the adsorptive properties of the zoogleal organisms for the removal of radioactive elements in waters relatively devoid of organic nutrients, common foods supplemented with essential minerals can be fed to maintain good control of the activated sludge process.

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TABLE 1

Mineral Analysis of Cincinnati Tap Water**

Results in p.p.m.

	Minimum	Maximum	Average
Total Solids	148	337	221
Total Hardness ($CaCO_3$)	96	162	119
Non-Carbonate Hardness ($CaCO_3$)	36	47	39
Calcium (Ca)	29	45.5	34.8
Magnesium (Mg)	5.5	11.7	7.8
Sulfate (SO_4)	65.3	109.5	81.6
Chlorides (Cl)	16	53	31
Iron (Fe)	Trace	0.2	0.2
Fluorides (F)	0.1	0.3	0.2
Phosphates (P)*	0	0.03	0.01
Potassium (K)*	1.7	3.5	2.2
Ammonia (N)*	0	0.06	0.03
Nitrates (N)*	Trace	0.4	0.2
Nitrites (N)*	0	0.007	0.002

(*) Analysis by our laboratory during the course of study.

(**) Data obtained from the Cincinnati Water Department for 1949 through the courtesy of Bruce Shuey.

TABLE 2

The B.O.D. (5-day, 20°C.) and Oxygen Consumed of Organic Nutrients in Formula "C" Water

Nutrient	Grams of O_2 Used per Gram Nutrient	
	B.O.D.	O.C.
Corn Meal	0.18	0.34
Graham Flour	0.74	0.82
Wheat Flour	0.65	1.26
Soya Flour	0.72	1.33
Dextrose	0.74	1.25
Nutrient Broth (Difco)	0.84	1.01

TABLE 3

The Effect of pH Control on Activated Sludge Supernatant*

	Sludge "A"		Sludge "B"	
pH Control	No	Yes	No	Yes
Supernatant Suspended Solids, p.p.m.	140	60	170	30
pH after 23 Hours Aeration, Average	6.6	7.6	6.3	7.6
Maximum	7.4	7.9	7.0	7.9
Minimum	3.9	6.7	3.6	6.9
Settleability, S.V.I., Average	69	52	49	56
Gain in Sludge Solids, mg/g. of Feed	310	270	290	260

(*) All sludges were fed 1,000 p.p.m. of a 3-1 ratio wheat flour-dextrose mixture daily. The dilution water for Sludge "B" contained 53 p.p.m. NH_4NO_3-N compared to 35 p.p.m. NH_4NO_3-N in Sludge "A".

TABLE 4

The Phosphorous and Nitrogen Requirements of Activated Sludge

Sludge Number	Minerals Added Per Day N_2 p.p.m.	Minerals Added Per Day P_4 p.p.m.	Aerator Suspended Solids: Range in Mixed Liquor g/liter	Aerator Suspended Solids: Ash on Dry Basis %	Aerator Suspended Solids: Gain in Sludge Solids p.p.m.	Supernatant*: Suspended Solids p.p.m.	Supernatant*: NO_3-N p.p.m.	Sludge Settleability S.V.I.
	2	3	4	5	6	7	8	9
			Twelve Feeds of 750 p.p.m. Wheat Flour and 250 p.p.m. Dextrose to Aerator Capacity per Day					
1	0	0	2.7-5.3	8.2	320	25	4.8	89
2	0	2.9	2.6-6.5	9.8	380	21	0.1	55
3	25	2.9	2.3-4.6	11.5	270	35	16	70
4	50	2.9	2.5-4.4	11.0	250	25	46	77
5	100	2.9	2.0-4.2	11.5	220	27	99	112
6	50	0	2.4-5.4	8.1	350	24	47	121
7	50	1.45	2.6-5.1	10.2	320	17	53	128
8	50	2.9	2.7-4.7	11.5	260	21	34	74
9	50	5.8	2.5-4.7	12.0	290	27	42	69
10	50	11.6	2.3-4.9	16.3	360	36	29	67
			Ten Feeds of 375 p.p.m. Wheat Flour and 125 p.p.m. Dextrose to Aerator Capacity per Day					
11	0	0	2.8-3.6	9.6	-25	130	0.3	79
12	0	2.9	4.2-5.1	8.4	95	44	Trace	44
13	12.5	2.9	2.4-2.8	11.7	45	98	21	49
14	25	2.9	2.5-3.0	11.2	25	58	38	65
15	50	2.9	2.3-3.1	11.2	65	40	100	117
16	100	2.9	2.5-2.7	10.2	5	110	84	66
17	25	1.45	2.9-3.3	8.9	20	36	75	249
18	25	2.9	2.5-3.0	12.9	30	48	37	61
19	25	5.8	2.6-3.4	16.2	85	56	40	52
20	25	11.6	2.9-4.5	35.7	135	84	36	44

(*) The pH of sludges ranged from 9.5 to 7.2

FIG. No.1

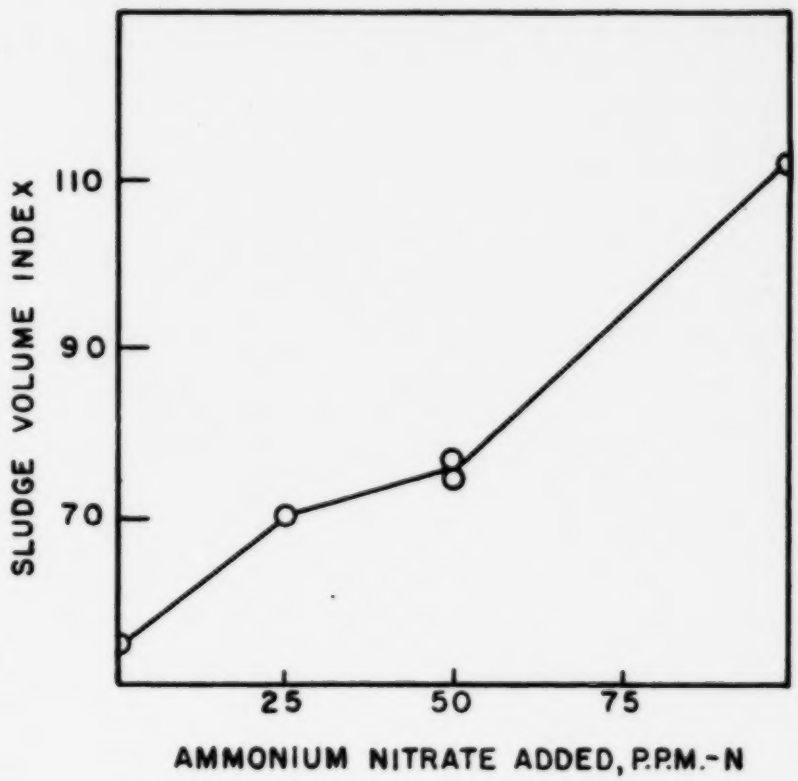
SLUDGE VOLUME INDEX
110
90
70
25
50
75
AMMONIUM NITRATE ADDED, P.P.M.-N

TABLE 5

The Nutritional Value of Potassium Additions

(Fifteen Feeds of 750 p.p.m. Wheat Flour and 250 p.p.m. Dextrose in Cincinnati Tap Water, pH Adjustment in Range 7.0-9.0 with NaOH)

Sludge Number	Potassium Added p.p.m.	Aerator Susp. Solids Range p.p.m.	Ash %	Gain p.p.m.	Supernatant Suspended Solids p.p.m.	Settleability Index S.V.I.
	2	3	4	5	6	7
	With 2.9 p.p.m. Phosphorous, no NH_4NO_3					
1	0	2.4-6.6	6.8	510	36	45
2	13.1	2.4-7.2	7.4	450	39	41
3	26.2	2.4-7.1	7.4	560	39	33
4	54.5	2.5-7.4	6.6	570	36	31
5	104.8	2.4-7.3	6.9	570	33	31
	With 50 p.p.m. NH_4NO_3, no phosphorous					
6	0	2.3-4.9	5.4	360	36	119
7	13.1	2.2-5.4	5.8	340	62	55
8	26.2	2.3-5.3	5.2	360	73	111
9	54.4	2.3-4.9	5.4	310	80	133
10	104.8	2.3-4.5	5.6	400	75	50
Avg. of Sludge Nos. 7-10				352	72	87

TABLE 6

Confirmation Experiment

	Period I	Period II
Duration of experiment, days	14	94
Capacity of Aerator, liters	16	16
Days when fed	11	79
Daily Feed		
(a) Wheat Flour, grams	9	12
(b) Dextrose, "	3	4
(c) PO_4-P "	0.05	0.05
(d) NaOH "	0.96	0.96
(e) Minerals, "	Note A	Note A
Aerator Suspended Solids, g/l.		
Normal range	3-4	4-6
Maximum	4.3	9.6
Minimum	2.9	2.3
Settleability of Mixed Liquor		
Average ml. per gram suspended solids,(S.V.I.)	77	67
No. days when higher than 100	1	3
No. days when higher than 150	0	1
Supernatant Quality		
Average suspended solids,p.p.m.	18	30
Average oxygen consumed,p.p.m.	-	34
Oxygen consumed removal,per cent of feed	-	96
No. days when S.S. > 30 p.p.m.	0	21
No. days when S.S. > 50 p.p.m.	0	10
No. days when S.S. > 100 p.p.m.	0	10
Gain in Aerator suspended solids. Mg. per gram of food added	30	394

Note A: Correction of unstable conditions obtained by the addition of 0.124 grams KCl-K in Period I and the periodic addition of a total of 7.36 grams of N as NH_4NO_3 and 0.34 grams KCl-K in Period II.